Small-scale Forestry (2013) 12:519–538
DOI 10.1007/s11842-012-9227-x

RESEARCH PAPER

Prioritizing Underutilized Tree Species for Domestication in Smallholder Systems of West Java

Budi H. Narendra · James M. Roshetko · Hesti L. Tata · Elok Mulyoutami

Accepted: 23 November 2012 / Published online: 28 November 2012
© Steve Harrison, John Herbohn 2012

Abstract This paper provides an overview of a tree species prioritization study of underutilized tree species in a participatory tree domestication program for smallholders in Indonesia. The study was conducted in three villages of Nanggung subdistrict, Bogor district via farmer surveys, focus group discussion, SWOT analysis and evaluation of markets and germplasm sources. Five priority species were identified: *Manglietia glauca*, *Parkia speciosa*, *Durio zibethinus*, *Gmelina arborea* and *Sandoricum koetjape*. These species are promising components of agroforestry systems to enhance smallholder livelihoods and can grow under the low management conditions common in smallholder systems. They represent indigenous and exotic tree types that produce timber, fruit or spices within the domestication continuum. Furthering the domestication and utilization of these species requires the identification and dissemination of available germplasm sources, the dissemination of high-quality germplasm and the development of farmer-friendly propagation and tree management practices. Also, as with most smallholder systems, the marketing practices for the products of these five species require improvement, starting with the production of reliable quantities of high quality tree products.

Keywords Species prioritization · Germplasm sources · Propagation · Tree management

B. H. Narendra (✉) · H. L. Tata
Research and Development Center for Conservation and Rehabilitation, Jalan Gunung Batu 5, Bogor, Indonesia
e-mail: budihadin@yahoo.co.id

J. M. Roshetko
WinrockInternational, Morrilton, AR, USA

J. M. Roshetko · H. L. Tata · E. Mulyoutami
World Agroforestry Centre (ICRAF), Southeast Asia Regional Office, PO Box 161, Bogor 16001, Indonesia

Introduction

Tropical rainforests of the Indo-Malayan region are endowed with a plethora of plant genetic resources that provide valuable and marketable timber, medicines, fruit and other products. There are more than 100,000 tree species worldwide (BGCI (Botanic Gardens Conservation International) 2007) but only 10,000 species have been described in detail (Reeb 1998). Of the more than 4,000 tree species in Indonesia, less than 10 % has been investigated in relation to their wood properties and utilization (Martawijaya et al. 2005). Smallholders and forest industries tend to utilize only a few timber species, including *Paraserienthes falcataria, Tectona grandis, Acacia mangium, Dalbergia latifolia* and *Swietenia macrophylla*. These species share the following characteristics: commonly available germplasm, ease in propagation and management, current market demand, known wood properties and promotion by government, non-government and development organizations. Other tree species are less understood or underutilized. Lesser known tree species are generally neglected or overlooked because they have not been exploited commercially, there is a lack of information regarding their use and little, if any, research has been conducted on them. They occur in the wild or are grown as scattered trees in tree garden systems. They are a source of useful genes for related crop species and hold promise for economic development (Normah 2003). Underutilized plant species are those currently of minor importance in terms of production, consumption (food or medicine) and utilization, and are not yet fully exploited in terms of contribution to market or household economies (Aboagye et al. 2007). In this study, the status of underutilized species focuses on the specific conditions of the study area, because in other locations the same species might be commonly or intensively utilized.

Tree domestication is accelerated anthropogenic evolution that brings species into wider cultivation through a farmer-driven or market-led process. The objective is to enhance tree performance in terms of improved tree products or environmental services as well as increasing species awareness and market orientation (Roshetko and Evans 1999; Simons and Leakey 2004). Tree domestication is an iterative process that involves species selection, production, management and adoption of desirable germplasm, to product marketing (Fig. 1). Some activities may be bypassed or occur in parallel during the domestication process. The progress may also flow back to earlier steps in the continuum as interest in or the economic value of a species develops further (Roshetko and Evans 1999).

Participatory tree domestication with farmers is a viable strategy to enhance livelihoods, address food security and promote sustainable environmental management (Akinnifesi et al. 2008; Tchoundjeu et al. 2010; Leakey et al. 2012). Farmers' active participation in tree domestication will increase efficiency and improve the applicability of results because they are best able to identify tree characteristics that will satisfy their needs and apply indigenous knowledge to guide tree management. In agroforestry, where systems and practitioners are highly heterogeneous, the choice of tree species is much more complex compared to classical plantation forestry. The farmers employ many distinct tree species, but little scientific information is available on them.

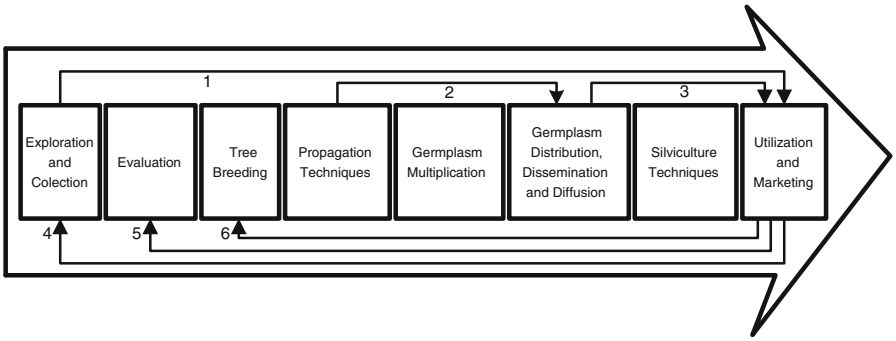

Fig. 1 Tree domestication continuum (Roshetko and Evans 1999)

In the past, researchers determined species priority based on their own interests, and views on species importance were probably the most important criteria (Franzel et al. 1996). Tree species selection, an iterative process of tree domestication, should be based on farmers' preferences, market demand or potential, germplasm availability and environmental suitability. Farmers should also determine the tree characteristics to be improved. Selection of fruit trees, for example, might be determined by fruit characteristics, tree growth, morphology and insect resistance (Simons 1996). Two common constraints for smallholders are lack of high quality planting material and the absence of well-functioning germplasm supply systems, Access to the germplasm can be improved via participatory domestication, training in germplasm management and introduction of more productive germplasm. Access to tree product markets can be enhanced by identifying new opportunities, sensitizing consumers, increasing value-chain transparency and providing training and credit for growers (Dawson et al. 2011).

In West Java, the traditional tree farming system called *dudukuhan* is divided into four types: (1) timber, (2) mixed fruit-timber-banana-annual crops, (3) mixed fruit-timber and (4) fallow (Manurung et al. 2008). Dudukuhans, like other tree farming systems in developing countries, are not managed intensively. Fertilizer application, weeding, thinning and pruning are usually conducted only when trees are intercropped with annual or seasonal crops. Harvesting products is often the most common management practice. As a result, the quality and quantity of products might be far below the systems' potential (Holding-Anyonge and Roshetko 2003; Michon 2005; Roshetko et al. 2007).

Dudukuhan systems in West Java are dominated by the timber species *Maesopsis eminii* (22.1 %) and *Paraserienthes falcataria* (14.4 %) and by banana varieties (*Musa* spp. 26.8 %). Diverse species account for the remainder of the systems, including *Artocarpus heterophyllus* (4.0 %), *Archidendron pauciflorum* (3.6 %), *Nephelium lappaceum* (3.3 %), *Mangifera odorata* (1.7 %), *Parkia speciosa* (2.2 %), *Sandoricum koetjape* (1.6 %) and *D. zibethinus* (1.5 %), but they only make minor contributions to farmers' livelihoods (Manurung et al. 2005). Manurung et al. (2008) theorized that dudukuhan productivity can be enhanced by improving farmers' management skills and developing tree polycultures based on four or five potential species through a tree domestication program.

This study identified underutilized tree species in West Java where further domestication could enhance the productivity of smallholder livelihood systems governed by agroforestry. The study commenced in December 2010 and ran until March 2011, involving farmer surveys, focus group discussions, market and germplasm surveys; strengths, weaknesses, opportunities and threats (SWOT) analysis and literature review. Data evaluation targeted recommendations for a participatory tree domestication program of dudukuhan systems. This paper reports the results of species selection, farmers' knowledge about the species, as well as availability of germplasm sources. Species selection intentionally included diverse tree types (both indigenous and exotic), those that produce timber, fruit or other products and others at various points on the domestication continuum.

Research Method

The study was conducted in Nanggung sub-district, Bogor district, West Java province. Nanggung is within easy reach of two cities (Bogor and Jakarta). Nanggung farmers are primarily smallholders with access to less than 1 ha of land. They have limited access to professional technical assistance and poor market linkages, particularly to lucrative urban and regional markets in Bogor and Jakarta (Roshetko et al. 2004a). Nanggung consists of 10 villages encompassing 11,000 km^2 and elevation ranges from 400 to 1,800 m (Fig. 2). Average landholding per household is 0.75 ha, of which 0.5 ha is given over to dudukuhan. Agricultural (31.2 %) and off-farm activities (61.5 %), remittances and miscellaneous earnings (7.3 %) are income sources (Budidarsono et al. 2006).

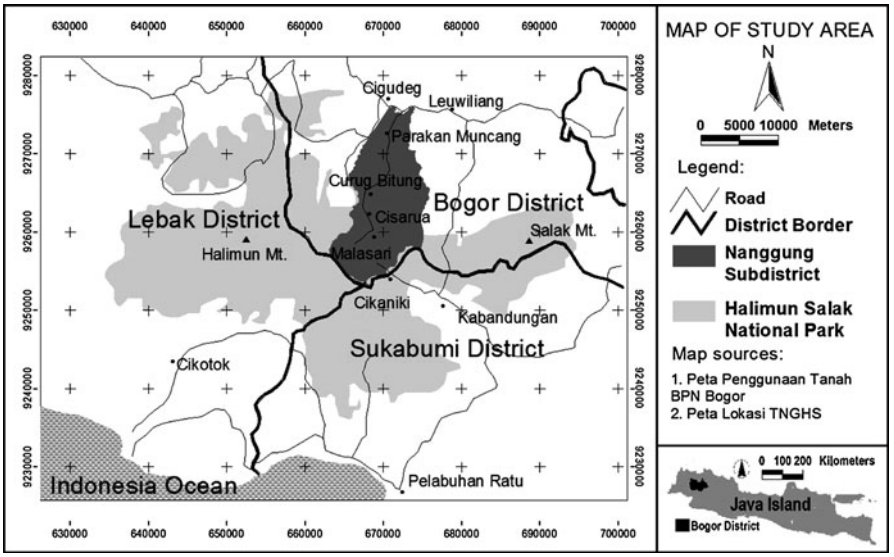

Fig. 2 Map of the study area

Farmer Surveys

Farmer surveys were conducted in Cisarua, Curug Bitung and Parakan Muncang villages, selected purposively as representative of the sub-district and their watershed position (upstream, mid-stream and downstream). Thirty households (10 in each village) were selected on the basis that tree species supported their livelihoods significantly. Data were collected through personal semi-structured interviews. Subjects included: tree species in the dudukuhan systems; farmer preferences of tree species for domestication; knowledge and steps in tree management practices; commercial value and market chains for each species as well as quality and availability of germplasm sources. Farmers were asked to consider less-familiar or less-utilized species that may have high economic potential, including species that have been exploited but need improvement for greater revenue.

Focus Group Discussion

Results from the farmer surveys were shared among 9 farmers from the 3 villages in a focus group discussion held in Parakan Muncang village. Each village was represented by 3 household heads. The objective was to determine 5 priority species for further domestication in the context of market and domestication potential. A list of preferred species identified during the surveys was displayed. The farmers were encouraged to consider diverse species types: indigenous and exotic, those that provide various products, those with potential to be improved and those with potential markets. They were also told that candidate species could be within the domestication continuum, but further improvement of the species used in smallholder systems was still possible. Farmers discussed the preferred species and selected 5 priority species.

SWOT Analysis

The 5 priority species were evaluated by the research team using weighted SWOT scoring analysis adapted from Flavel and Williams (1996). Strengths and weaknesses (species characteristics influencing the selection of species) were identified based on respondents' knowledge of the tree species to be domesticated. The same process was used to identify opportunities and threats (external factors influencing the selection of species). Each SWOT category was weighted based on importance against other categories out of a total score of 1.0. Each individual strength, weakness, opportunity and threat was also given a score, a percentage value out of a maximum of 100 %, to indicate its level of importance. Final scores for each species in each category were calculated by multiplying the score by the weighting attributed to the relevant category to produce a weighted importance level for that category. The priority species were compared by checking each species coordinate ($x = a - b; y = c - d$).

Market and Germplasm Surveys

Market and germplasm surveys were conducted to identify the commercial value and markets of selected species, as well as possible germplasm sources. Sixteen

traders were interviewed: 3 handled timber products, 4 fruits, 3 spices, 5 both fruits and spices, and 1 all types. Information collected in this interview included the cost of tree products, market linkages, traders, origin of goods, and product prices at each step along the market chain. Information regarding the availability of germplasm sources of each species was collected from farmers, staff of the Halimun Salak National Park, the Forestry Research and Development Agency (FORDA) and from a review of the directory of tree seed suppliers in Indonesia (complied by Roshetko et al. 2003). Subsequently, all potential germplasm sources near Nanggung were visited to obtain information from landowners or institutional staff. Sources included farms, plantations, forests and commercial seed suppliers.

Results

A total of 44 tree species were identified for domestication. including fruit tree species (38.6 %), timber species (47.7 %) and spice species (13.6 %). Respondents identified 45,767 woody trees on their farms, 3.9 % being fruit trees, 90.3 % timber trees and 5.9 % spice trees. Although timber species represented less than half of the total species, they accounted for 90 % of the trees on the farms. As seen in Table 1, Curug Bitung has the greatest species diversity, total number of trees and tree density, while Cisarua has the lowest number for most categories. The number of trees per household ranged from 50 in Parakan Muncang to 9,680 in Curug Bitung.

All respondents cultivated *P. falcataria,* which accounts for 46.0 % of total trees. *Maesopsis eminii* was the second most common species, cultivated by 90 % of respondents and accounting for 28.6 % of the total (Table 2). Common fruit tree species in dudukuhans were *Garcinia mangostana* (39.6 % of all fruit tree), *Artocarpus heterophyllus* (27.8 %) and *D. zibethinus* (7.7 %), while *c*ommon spice species were *Coffea robusta* (74.4 % of all spice trees), *P. speciosa* (10.9 %) and *Archidendron pauciflorum* (9.2 %).

Farmers primarily used fruit and spice tree products for household consumption, with small quantities sold in local markets or to local traders. The farmers prioritized 27 tree species (Table 3), which included fruit, spice and timber tree

Table 1 Tree density and tree species in each study area

Characteristic	Village		
	Cisarua	Curug Bitung	Parakan Muncang
Study area (ha)	14.8	21.1	9.6
Tree density (trees/ha)[a]	314	1,470	1,059
Number of tree species[b]	19	36	30
Number of trees	4,664	30,934	10,169
Most trees owned	880	9,680	5,330
Least trees owned	84	824	50
Average trees owned	466	3,093	1,016

[a] Total tree number of 10 respondents divided by total land area of those respondents

[b] This includes all woody trees

species. Trees in the dudukuhans originated from either natural regeneration or from planting. Wealthy farmers usually purchased seedlings from a supplier, while most farmers transplanted wildlings. Some farmers produced limited numbers of seedlings for themselves, primarily fruit and spice species, in small backyard nurseries.

The focus group discussion identified five species, in the following order of preference, for further domestication: *M. glauca*, *P. speciosa*, *D. zibethinus*, *G. arborea* and *S. koetjape*. Farmers and researchers felt that these are species that yield both long- and short-term products and offer a potential advantage for smallholder production. *Manglietia glauca* and *G. arborea* represent timber species, *D. zibethinus* and *S. koetjape* are fruit species and *P. speciosa* is a spice species. Except for *G. arborea*, they are indigenous to the Nanggung area. *Manglietia glauca* and *Sandoricum koetjape* have not yet benefited from domestication activities and are infrequently planted. *Parkia speciosa* has benefited from some domestication and is commonly planted in small numbers. *Durio zibethinus* and *G. arborea* have been more widely domesticated, with improved germplasm and management prescriptions, but these advances rarely reach farmers. Strong demand for *P. speciosa*, *D. zibethinus* and *G. arborea* across national, provincial and local markets is a significant opportunity for smallholder production. *Sandoricum koetjape* was selected as a species with cultural or traditional value and niche market potential that would not attract competition from the formal horticulture sector. Some fruit tree species in the priority list were not selected because the formal horticulture sector (including importers) is believed to maintain a strong market position.

The market survey focused on the 5 selected species. A number of farmers in Cisarua and Curug Bitung planted 10 to 40 *M. glauca* seedlings in 2008 and 2009. They did not produce seedlings themselves due to insufficient seed and propagation knowledge. As with other tree species, *M. glauca* seedlings are planted early in the rainy season. Land preparation, including the preparation of 400 planting holes, requires 25 labour days/ha. Farmers recommended the application of 2 kg manure per planting hole. Weeding was recommended 6 and 12 months after planting, requiring 10 labour days/ha. *Manglietia glauca* has been successfully harvested and sold by a small number of Nanggung farmers. As in most smallholder timber production systems, *M. glauca* is sold when farmers need cash—economic maturity is not considered. Farmers sell the standing trees to middlemen or directly to sawmill owners. The buyer is responsible for cutting and transporting the timber.(Table 4).

The pods are the key product of *P. speciosa.* When tree pod production begins to decline, usually at about 20 years of age, *P. speciosa* can be harvested for timber. Although wood quality is inferior to *P. falcataria* the selling price is approximately the same.

Marketing systems for *D. zibethinus* are underdeveloped. Fruit is usually sold to traders while green and still on the tree—an arrangement called *ijon* (from the Indonesian word *hijau*, meaning green). Farmers receive cash payment when an agreement is reached. They are not responsible for further management, nor liable if the crop fails. The disadvantage of this marketing system is that farmers receive less than half the value of the crop. Traders sell most of the fruit to lucrative urban

Table 2 Species composition in each village

Local/English/ botanical name	Main product	Number of respondents owning the species	Tree density (trees/ha)				Fraction of total trees (%)
			Cisarua	Curug Bitung	Parakan Muncang	Average	
Manggis/Mangosteen/ *Garcinia mangostana* Linn.	Fruit	18	4	4	58	22	1.529
Nangka/Jackfruit/ *Artocarpus heterophyllus* Lam.	Fruit	15	3	13	18	11	1.073
Durian/Durian/*Durio zibethinus* Murr[a]	Fruit	14	3	3	2	3	0.299
Jambu batu/Guava/ *Psidium guajava* Linn.	Fruit	2	9	0	0	3	0.284
Rambutan/ Ramboostan/ *Nephelium lappaceum* Linn.	Fruit	11	2	1	2	1	0.135
Melinjo/Gnetum/ *Gnetum gnemon* Linn.	Fruit	2	0	1	3	2	0.131
Kelapa/Cocos/*Cocos nucifera* Linn.	Fruit	6	0	2	1	1	0.131
Mangga/Manggo/ *Mangifera indica* Linn.	Fruit	8	0	1	2	1	0.107
Kecapi/Santol/ *Sandoricum koetjape* (Burm.f.) Merr[a]	Fruit	4	0	0	1	1	0.037
Duku/Langsat/ *Lansium domesticum* Corr.	Fruit	5	0	0	1	0	0.031
Aren/Sugar palm/ *Arenga pinnata* (Wurmb.) Merr.	Fruit	2	0	1	0	0	0.026
Kweni/Kueni/ *Mangifera odorata* Griff.	Fruit	3	0	0	1	0	0.022
Alpukat/Avocado/ *Persea americana* Mill	Fruit	2	0	0	1	0	0.02
Kemang/Kemang/ *Mangifera kemanga* Blume	Fruit	2	0	0	1	0	0.015
Sukun/Bread fruit/ *Artocarpus altilis* (Parkinson) Fosberg	Fruit	2	0	0	1	0	0.013

Table 2 continued

Local/English/ botanical name	Main product	Number of respondents owning the species	Tree density (trees/ha)				Fraction of total trees (%)
			Cisarua	Curug Bitung	Parakan Muncang	Average	
Lengkeng/Longan/ *Euphoria longana* (Lour.) Steud.	Fruit	1	0	0	0	0	0.009
Jeruk/Citrus/*Citrus microcarpa* Linn.	Fruit	1	0	0	0	0	0.002
Fruit tree density (trees/ha)			1.2	1.5	5.4	2.6	3.86
Kopi/Coffee/*Coffea robusta* Lindl, ex De Willd	Spice	2	0	95	0	32	4.37
Jengkol/Ngapi nut/ *Archidendron pauciflorum* (Benth.) Nielsen	Spice	14	1	9	4	5	0.54
Cengkeh/Clove/ *Syzygium aromaticum* (Linn.) Merr.	Spice	5	0	3	4	2	0.205
Pala/Nutmeg/ *Myristica fragrans* Houtt.	Spice	5	0	3	0	1	0.122
Kluwak/Football fruit/ *Pangium edule* Reinw.	Spice	1	0	0	0	0	0.002
Petai/Stinky bean/ *Parkia speciosa* Hassk.[a]	Spice	19	1	10	7	6	0.638
Spice tree density (trees/ha)			0.3	20.0	2.5	7.7	5.88
Sengon/Albizzia/ *Paraserienthes falcataria* (L.) Nielsen	Timber	30	169	583	652	468	46.01
Kayu afrika/Manii/ *Maesopsis eminii* Engl.	Timber	27	76	457	241	258	28.6
Mahoni/Mahogany/ *Swietenia macrophylla* King	Timber	11	7	162	8	59	7.87
Meranti/Shorea/ *Shorea* spp.	Timber	6	1	40	1	14	1.879
Puspa/Needlewood/ *Schima wallichii* Noronha	Timber	11	23	10	21	18	1.645

Table 2 continued

Local/English/ botanical name	Main product	Number of respondents owning the species	Tree density (trees/ha)				Fraction of total trees (%)
			Cisarua	Curug Bitung	Parakan Muncang	Average	
Suren/Red cedar/ *Toona sureni* (Bl.) Merr	Timber	11	4	21	0	8	1.112
Mangium/Mangium/ *Acacia mangium* Willd	Timber	3	0	9	21	10	0.885
Ki Sampang/Pepau/ *Euodia latifolia* DC.	Timber	7	7	4	3	4	0.437
Jati/Teak/*Tectona grandis* Linn. F.	Timber	2	0	9	0	3	0.437
Mindi/Neem/*Melia azedarach* Linn.	Timber	4	0	8	1	3	0.393
Gmelina/Gmelina *Gmelina arborea* Roxb.[a]	Timber	5	0	7	1	3	0.367
Manglid/Magnolia/ *Manglietia glauca* Blume.[a]	Timber	6	4	3	0	2	0.284
Rasamala/Rasamala/ *Altingia excelsa* Noronha	Timber	2	0	1	3	1	0.109
Pulai/Dita bark/ *Alstonia scholaris* (L.) R.Br.	Timber	1	0	1	0	0	0.066
Pinus/Pine/*Pinus merkusii* Jungh. and De Vr.	Timber	1	0	1	0	0	0.044
Jabon/Cadamba/ *Anthocephalus cadamba* (Roxb.) Miq.	Timber	1	0	1	0	0	0.033
Kamfer/Camphoor/ *Dryobalanops aromatica* Gearth.	Timber	2	0	1	0	0	0.028
Karet/rubber/*Hevea brasiliensis* Muell. Arg.	Timber	1	0	0	1	0	0.022
Sungkai/False elder/ *Peronema canescens* Jack	Timber	1	0	0	0	0	0.022
Ki Huru/Litsea/*Litsea noronhae* Blume	Timber	1	0	0	1	0	0.011
Lamtoro/Leucaena/ *Leucaena leucocephala* (Lam.) de Wit	Timber	1	0	0	0	0	0.004

Table 2 continued

Local/English/ botanical name	Main product	Number of respondents owning the species	Tree density (trees/ha)				Fraction of total trees (%)
			Cisarua	Curug Bitung	Parakan Muncang	Average	
Timber tree density (trees/ha)			13.9	62.8	45.4	40.5	90.26
Total		4,664	30,934	10,169	45,767		

[a] Species were selected for further domestication by farmers during discussions

markets. *Durio zibethinus* timber also has higher market value, but a longer rotation, than *P. falcataria* or *M. eminii*.

Gmelina arborea is a popular species in Nanggung. The market price for the timber is similar to that of *P. falcataria* and there is a steady demand at the village level and from local commercial sawmills.

Local niche markets exist for *S. koetjape* fruit, where demand exceeds supply. Stable market prices for 'sweet *kecapi*' fruit have not yet developed due to inconsistent supply and quality. *Sandoricum koetjape* is valued for its timber (quality and price are similar to *D. zibethinus*).

SWOT analysis results for the five species are reported in Table 5. *Gmelina arborea* and *P. speciosa* showed strength and opportunity for domestication. Smallholder domestication of these species may be easier than for the other three species. *Manglietia glauca* and *S. koetjape* have positive strength, but threats are greater than opportunities. Germplasm sources of *M. glauca* are threatened by illegal logging; market opportunities for the timber are still uncertain compared to common fast-growing timber species with established markets including *G. arborea* and *P. falcataria*. *S. koetjape* is constrained by lack of technology and knowledge related to post-harvest handling and processing. This results in low fruit prices during the peak harvesting season. *Durio zibethinus* has ample opportunity but there is a long juvenile period, especially for local cultivars.

The germplasm survey revealed that indigenous sources of *M. glauca* could be found in Gunung Halimun Salak National Park (Priyadi et al. 2010). Respondents indicated that the species is now difficult to find in the Halimun area, the natural forest closest to Nanggung. Park officers reported that *M. glauca* still grows in the Salak mountain area in Sukabumi district. The research team observed that some *M. glauca* trees were growing in the Nanggung area, which may be an alternative germplasm source.

Although high-yielding local individual trees and commercial varieties of *P. speciosa* were known, most farmers did not consider the genetic quality of their planting material. Some *P. speciosa* trees with good phenotypic characteristics were observed in Parakan Muncang village. These specimens can produce 3,000 pods per year and have large seeds, and could serve as a local seed source. Besides transplanting wild seedlings of *P. speciosa* on their land, some farmers practice an indigenous propagation method where the seed coats are removed and seeds are cut before sowing to accelerate germination (Roshetko et al. 2008).

Table 3 Tree species prioritized by farmers

Botanical name	Number of farmers			Total
	Cisarua	Curug Bitung	Parakan Muncang	
Manglietia glauca Blume.	7	7	3	17
Garcinia mangostana L.	6	6	3	15
Nephelium lappaceum L.	4	4	6	14
Parkia speciosa Hassk.	5	3	4	12
Mangifera indica L.	1	3	4	8
Artocarpus altilis (Parkinson) Fosberg	6	2	0	8
Myristica fragrans Houtt.	0	6	0	6
Durio zibethinus Murr.	1	2	2	5
Gmelina arborea Roxb	2	1	0	3
Archidendron pauciflorum (Benth.) Nielsen	2	0	1	3
Shorea spp.	2	1	0	3
Acacia mangium Willd	2	1	0	3
Swietenia macrophylla King	0	0	2	2
Citrus aurantifolia (Christm.) Swingle	2	0	0	2
Anthocephalus cadamba (Roxb.) Miq.	0	2	0	2
Paraserienthes falcataria (L.) Nielsen	1	0	0	1
Psidium guajava Linn.	0	1	0	1
Persea americana Mill	0	0	1	1
Maesopsis eminii Engl.	1	0	0	1
Toona sureni (Bl.) Merr	0	1	0	1
Citrus microcarpa L.	0	0	1	1
Altingia excelsa Noronha	0	0	1	1
Manilkara zapota (L.) van Royen	1	0	0	1
Tectona grandis Linn. F.	0	1	0	1
Syzygium aqueum (Burm.f.) Alston	0	0	1	1
Melia azedarach L.	0	1	0	1
Alstonia scholaris (L.) R.Br.	0	1	0	1

Durio zibethinus trees originated from the chance introduction of seeds, seedlings and wildings. Despite the existence of many local and exotic varieties that produce superior fruits, most farmers do not consider genetic quality when cultivating *D. zibethinus*. Local superior varieties of *D. zibethinus* are recognized, but are not necessarily those that are cultivated.

Trials conducted by FORDA at their research forests in Haurbentes (Jasinga sub-district) and Parung Panjang (Parung Panjang sub-district) identified suitable *G. arborea* material for Bogor district. It was observed in Haurbentes that provenance no. 4045 (origin Sankos, India) and no. 4004 (origin Chinsapo, Malawi) had optimal growth in terms of height and diameter (Suhaendi 1989). The Parung Panjang trials demonstrated that the progeny of *plus trees* from East Java, Central Java and East

Table 4 General information on selected tree species

Species	Tree origin	Product and price	Germplasm sources
M. glauca	Local markets or commercial nurseries Rp 1,300/seedling	Trees are harvested at a minimum dbh of 18 cm (at an approximate age of 10 years) Standing trees with a 25 cm dbh are sold for Rp 230,000[a]	Salak National Park. Scattered trees in Nanggung district.
P. speciosa	Natural regeneration protected and/or transplanted.	Trees with a dbh of 50 cm produce 30 bunches of 100 pods. Pods contain 11–20 seeds Pods are sold to traders for Rp 100,000–200,000/bunch The price in local markets is Rp 1,000–2,500/pod and in Bogor markets Rp 2,000–3,000/pod Standing trees with a 25 cm dbh are sold for Rp 50,000–60,000 (similar to *P. falcataria*)	Some trees in Parakan Muncang
D. zibethinus	Natural regeneration protected and/or transplanted	Trees with a dbh of 50 cm produce 50–100 fruits/year The *ijon* price is Rp 500,000/tree/season Climbers harvest fruit for Rp 400/fruit or Rp 20,000/day Fruits are sold in local markets for Rp 6,000–30,000/fruit and in Bogor or Jakarta markets for Rp 20,000–60,000/fruit Standing trees with a 10−25 cm dbh are sold for Rp 25,000–50,000	Some trees in Parakan Muncang
G. arborea	Historically free seedlings were distributed by government agencies or NGOs	Standing trees with a 25 cm dbh are sold for Rp 50,000–60,000 (similar to *P. falcataria*)	Haurbentes and Parung Panjang research forests
S. koetjape	Natural regeneration protected and/or transplanted.	Mature trees produce 10 sacks (25 kgs) of fruit per season Fruits are sold to traders for Rp 30,000/sack Fruits are sold in local markets for Rp 2,000–2,500/kg and in Bogor markets for Rp 5,000/kg Stable market prices for sweet varieties have not developed yet	Some trees in Parakan Muncang

dbh diameter at breast height

[a] $1 US 9,600 Indonesian Rupiah, as at November 2012

Kalimantan perform particularly well in Bogor. Despite these results, farmers in Nanggung plant *G. arborea* germplasm of unknown quality and origin, using whatever seed is available.

Table 5 SWOT analysis of selected species

Category	Sub-category	Weight	Score				
			M	G	D	P	S
Strength	1. Increases household income	0.50	80	40	60	80	20
	2. Easy to cultivate	0.30	20	40	100	80	60
	3. Low input in species planting	0.20	60	80	20	40	100
		a = score × weight	58	48	64	72	48
Weakness	1. Low quality product	0.25	20	40	60	80	100
	2. Long rotation (slow growth)	0.60	60	40	80	60	60
	3. Seed handling	0.15	100	40	60	40	60
		b = score × weight	56	40	72	62	70
		x = a − b	2	8	−8	10	−22
Opportunity	1. Farmers prefer to domesticate	0.30	100	40	60	80	20
	2. Institutions are targeting the species to be domesticated	0.05	20	100	80	60	40
	3. Farmers can cultivate the species	0.10	40	20	80	80	60
	4. Secure germplasm source	0.15	20	100	80	60	40
	5. High demand for the product	0.40	60	40	100	80	20
		c = score × weight	62	50	82	76	28
Threat	1. Loss of germplasm source	0.15	100	20	40	60	80
	2. Poor market linkages	0.20	100	80	60	20	40
	3. Lack of product processing technology	0.10	60	40	20	80	100
	4. Pests and diseases	0.25	40	60	80	100	20
	5. Uncertainty of product price	0.30	40	20	60	80	100
		d = score × weight	63	44	58	70	65
		y = c − d	−1	6	24	6	−37

M, *M. glauca*; G, *G. arborea*; D, *D. zibethinus*; P, *P. speciosa*; S, *S. koetjape*

Sandoricum koetjape is generally cultivated by transplanting wildlings. In Parakan Muncang there are local village varieties of sweet kecapi that have potential as a higher-value market product. However, certified germplasm of sweet kecapi is unavailable and it is not multiplied by vegetative propagation.

Discussion

Indonesian institutions involved in a Southeast Asian tree domestication study identified *P. speciosa*, *D. zibethinus*, *G. arborea* and *S. koetjape* as focal species. They also identified nursery management, tree propagation, germplasm distribution, tree management and product marketing as priorities for smallholder tree domestication. An additional priority for Indonesia was the production and distribution of technical information (Gunasena and Roshetko 2000).

In 1997, the Research and Development Center for Forest and Nature Conservation, an institution under FORDA prioritized fruit and timber species for smallholder tree domestication. *Durio zibethinus* was identified as a priority fruit species and *P. speciosa* as a priority timber species with multiple uses. The Forestry Seed Technology Center, also under FORDA, focused on *D. zibethinus* as a priority fruit species and *G. arborea* as a high-value timber species (Roshetko and Evans 1999).

An overview of these species in the context of local knowledge and domestication steps to further enhance their productivity in smallholder agroforestry systems is provided here.

Manglietia glauca

Manglietia *glauca* is a native but uncommon species in forests and tree gardens of West Java. About 20 % of the respondents reported *M. glauca* in their dudukuhan systems, but the species comprises only 0.3 % of the tree population. The use of *M. glauca* for land reclamation was initiated by PT Antam (Persero) Tbk, a gold mining company in eastern Nanggung. Farmers were enthusiastic about *M. glauca* because of the strong market demand for high quality timber. Although *M. glauca* has a longer rotation compared to *P. falcataria* or *M. eminii*, farmers wanted to domesticate *M. glauca* as a long-term investment and keep growing *P. falcataria* or *M. eminii* as short-term investment.

The SWOT analysis revealed that *M. glauca*'s greatest shortcomings are its recalcitrant seed and dearth of germplasm owing to its limited natural population, which is threatened by illegal harvesting in protected forests. Domestication of *M. glauca* should start with the identification and collection of germplasm. Remnant populations of *M. glauca* in the Mount Halimun and Salak National Park should be mapped and evaluated as germplasm sources. Park staff and local farmers who know these sites could assist in the process. Other domestication priorities are developing suitable propagation methods, making growth comparisons of provenances and development of management practices.

Parkia Speciosa

Parkia speciosa is not a new species in the Nanggung community. About 17 % of the respondents cultivated *P. speciosa* but the species accounts for only 0.6 % of dudukuhan trees. Manurung et al. (2005) reported that *P. speciosa* was the ninth most common tree species in Nanggung, comprising 2.2 % of all trees. Even under that limited level of cultivation, *P. speciosa* could provide 10 % of non-timber income from tree gardens, 3 % of agricultural income and 1 % of overall household income (Budidarsono et al. 2006). The main product of this species is the pods with edible seeds, which are consumed as a fresh or cooked vegetable and have many uses as a traditional medicine. Farmers favour *P. speciosa* because they are familiar with the species; demand for pods exceeds supply in local and regional markets resulting in a high price margin for farmers.

There is relatively little planting of *P. speciosa* in Nanggung because the commercial production of dudukuhans is oriented to timber production. *Parkia speciosa* showed high potential for increased domestication, with high product demand, farmers' interest in the species, potential for expanding on-farm populations and existence of underexploited high-yielding genetic material. Domestication efforts for *P. speciosa* aim to shorten the non-productive period, improve productivity and reduce the risk of pest and diseases (a significant threat according to the SWOT analysis). These efforts should focus on improving propagation techniques, selecting and collecting local and commercial varieties, and developing improved management practices. Farmers and researchers have expressed interest in increasing yield or seedling quality by grafting high-yielding material onto root stock of local varieties. Thus farmers need to adopt nursery management practices that produce high-quality seedlings. There is potential for farmers to sell quality *P. speciosa* seedlings to government, private sector and farmer clients (Roshetko et al. 2004a).

Durio zibethinus

Like *P. speciosa*, *D. zibethinus* is common in Nanggung. Manurung et al. (2005) found that *D. zibethinus* comprised 1.5 % of dudukuhan trees and accounted for 27.8 % of species composition in dudukuhan systems (Budidarsono et al. 2006). Domestication of *D. zibethinus* should focus on the dissemination of high-quality varieties and commercial recognition of local varieties, processes that interest Nanggung farmers. Based on the research team's observations, in Parakan Muncang alone there are 10 local *D. zibethinus* varieties that have superior quality and taste as well as thick flesh. Additional domestication efforts could focus on extending vegetative propagation and management practices to smallholders (Purnomosidhi et al. 2007).

Gmelina arborea

Gmelina arborea is easy to cultivate and is widely grown in South and Southeast Asia. It grows well under low management conditions and requires no soil amendments on reasonably fertile sites; however it performs poorly on degraded infertile sites and at altitudes over 800 m. It is a common species in government planting programs and industrial plantations in Indonesia, but has yet to achieve wide popularity among farmers in Nanggung. It has become popular with farmers in Nusa Tenggara (Roshetko et al. Roshetko and Mulawarman 2004b) and is cultivated by farmers in Lampung, but to a lesser extent than *P. falcataria* or teak (Tukan et al. 2004). *Gmelina arborea* was introduced to Nanggung recently. About 17 % of the surveyed farmers claimed to cultivate *G. arborea*, but the dudukuhan inventory conducted by Manurung et al. (2005) found no *G. arborea* in Nanggung. Farmers were interested in *G. arborea* as a replacement for *P. falcataria* which was dying out because of the gall rust disease outbreak in West Java in 2008 (Rahayu et al. 2010). According to farmers' perceptions, besides pest resistance, *G. arborea* has a straighter bole and higher quality wood than *P. falcataria*, but slightly slower

growth. The rotation age was reported to be 8–12 years by farmers in Lampung (Yuliyanti 2000), 7–10 years by the forest industry (Roshetko et al. 2002) and 8–12 years in the Philippines (Bertomeu et al. 2011).

Smallholder domestication efforts for *G. arborea* should focus on access to and dissemination of high quality seeds and comparison trials of promising provenances and landraces. This is a prudent first step because most *G. arborea* seed available in Indonesia is of uncertain quality, yet superior sources of germplasm do exist (Roshetko et al. 2002). The best material in Jasinga trials could serve as a superior local seed source. Domestication efforts should also focus on developing smallholder silvicultural practices that improve growth and quality of *G. arborea* and planting models that integrate long-and short-rotation timber species.

Sandoricum koetjape

Sandoricum koetjape is considered a native but minor forest and tree garden component in Nanggung. Only 13 % of the farmers reported *S. koetjape* on their farms. The species comprised 1.6 % and 1.9 % of dudukuhan trees according to Manurung et al. (2005) and Budidarsono et al. (2006) respectively. *Sandoricum koetjape* is underutilized compared to *D. zibethinus* and other fruit species because of its sour taste and lower market value. However, many *S. koetjape* trees in Nanggung are reported to produce sweet fruit which has high local demand. Farmers are interested in domesticating *S. koetjape* because of its large sweet fruit, with thick flesh and small seeds. *Sandoricum koetjape* is also valued for its timber which is easy to work and polish.

Domestication efforts should focus on germplasm sources that produce consistently large sweet fruit with thick flesh. A number of such trees are reported to grow in Parakan Muncang and other parts of Nanggung. To multiply sweet kecapi germplasm quickly, farmer-friendly vegetative propagation methods will be required, as well as improved tree management practices. Subsequent efforts should focus on developing recognition of sweet kecapi varieties.

Conclusions

The productivity of smallholder agroforestry systems can be enhanced through the domestication of underutilized species. In the context of participatory domestication the definition of 'underutilized species' includes species that may be exploited in commercial sectors but do not currently approach their potential in smallholder agroforestry systems. Farmers prioritized *M. glauca, P. speciosa*, *D. zibethinus*, *G. arborea* and *S. koetjape* for domestication. All five species hold promise for multi-species, multi-product agroforestry to enhance smallholder livelihoods and can grow under the low management conditions common in smallholder systems. They represent an array of indigenous and exotic tree types that produce timber, fruit or spices and those at various points on the domestication continuum.

Parkia speciosa, *D. zibethinus* and *G. arborea* are well-known species with commercial value but are not fully exploited at the smallholder level. *M. glauca* and

S. koetjape are indigenous species that are underexploited at all levels. *D. zibethinus* and *S. koetjape* primarily produce fruit. *P. speciosa* produces a spice. *Manglietia glauca* and *G. arborea* are long- and short-rotation timber species respectively. Furthering the domestication and utilization of these species requires the identification and dissemination of available high-quality germplasm sources and the development of farmer-friendly propagation and tree management practices. The marketing practices for the products of these five species could be improved by farmers taking a more active role, starting with the production of reliable quantities of high-quality products. These issues are best addressed through a participatory domestication approach in which farmers and researchers collaborate to develop and implement a species-specific tree domestication program. This process has already begun through the prioritization process reported in this paper.

Acknowledgments The authors would like to acknowledge the contributions of all respondents involved in the study. We thank Andi Margono for field assistance, staff of Halimun Salak National Park and FORDA, as well as Ramni Jamnadass of the World Agroforestry Centre (ICRAF) in Nairobi, Kenya for guidance and financial support.

References

Aboagye LM, Obirih-Opareh N, Amissah L, Adu-Dapaah H (2007) Analysis of existing national policies and legislation that enable or inhibit the wider use of underutilized plant species for food and agriculture in Ghana. Council for Scientific and Industrial Research, Accra

Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR (eds) (2008) indigenous fruit trees in the tropics: domestication, utilization and commercialization. CAB International, Wallingford

Bertomeu M, Roshetko JM, Rahayu S (2011) Optimum pruning intensity for reducing crop suppression in a gmelina-maize smallholder agroforestry system in Claveria Philippines. Agrofor Sys 83(2):167–180

BGCI (Botanic Gardens Conservation International) (2007) Tree-BOL to barcode world's 100,000 trees. http://www.bgci.org/. Accessed 10 Aug 2011

Budidarsono S, Wijaya K, Roshetko JM (2006) Farm and household economic study of *kecamatan* Nanggung, Kabupaten Bogor, Indonesia: a socio-economic baseline study for agroforestry innovations and livelihood enhancement. ICRAF working paper no. 19, World Agroforestry Center (ICRAF), Bogor, Indonesia

Dawson IK, Vinceti B, Weber JC, Neufeldt H, Russell J, Lengkeek AG, Kalinganire A, Kindt R, Lillesø JB, Roshetko JM, Jamnadass R (2011) Climate change and tree genetic resource management: maintaining and enhancing the productivity and value of smallholder tropical agroforestry landscapes. A rev Agrofor Sys 81(1):67–78

Flavel R, Williams J (1996) Strategic management: a practical approach. Prentice Hall, Sydney

Franzel, S., Jaenicke H, Janssen W (1996) Choosing the right trees: setting priorities for multipurpose tree improvement. ISNAR research report no. 8. International Service for National Agricultural Research, The Hague

Gunasena HPM, Roshetko JM (2000) Tree domestication in Southeast Asia: results of a regional study on institutional capacity for tree domestication in national programs. World Agroforestry Centre (ICRAF), Bogor, Indonesia

Holding-Anyonge C, Roshetko JM (2003) Farm-level timber production: orienting farmers towards the market. Unasylva 54(212):48–56

Leakey RBB, Weber JC, Page T, Cornelius JP, Akinnifesi FK, Roshetko JM, Tchoundjeu Z, Jamnadass R (2012) Tree domestication in agroforestry: progress in the second decade. In: Nair PKR, Garrity DP (eds) The future of agroforestry. Springer, New York, pp 145–173

Manurung G, Roshetko JM, Budidarsono S, Tukan JC (2005) Dudukuhan: traditional tree farming systems for poverty reduction. In: van der Ploeg J, Masipiquena, AB (eds). The future of the Sierra

Madre: responding to social and ecological changes. Proceedings of the 5th international conference on environment and development. Cagayan Valley Program on Environment and Development (CVPED). Golden Press, Tuuegarno, the Philippines, pp 90–110

Manurung G, Roshetko JM, Budidarsono S, Kurniawan I (2008) Dudukuhan tree farming systems in West Java: how to mobilize self-strengthening of community-based forest management? In: Snelder DJ, Lasco RD (eds) Smallholder tree growing for rural development and environmental services. Springer Science + Business Media B.V, New York, pp 99–116

Martawijaya A, Kartasujana I, Kadir K, Prawira SA (2005) Atlas kayu Indonesia jilid I. Badan Penelitian dan Pengembangan Kehutanan, Bogor

Michon G (2005) Domesticating forests: how farmers manage forest resources. CIFOR and World Agroforestry Centre (ICRAF). Nairobi, Kenya

Normah MN (2003) ruits of tropical climates - lesser-known fruits of Asia. In: Encyclopedia of food sciences and nutrition second edition. Academic Press, Amsterdam, p 2816

Priyadi H, Takao G, Rahmawati I, Supriyanto B, Nursal WI, Rahman I (2010) Five hundred plant species in Gunung Halimun Salak National ParkWest Java. Center for International Forestry Research, Bogor

Purnomosidhi P, Suparman, Roshetko JM, Mulawarman (2007) Perbanyakan dan budidaya tanaman buah-buahan: Pedoman lapang edisi kedua. World AgroforestryCentre (ICRAF), SEA Regional Office and Winrock International, Bogor, Indonesia

Rahayu S, Lee SS, Shukor NAA (2010) *Uromycladium tepperianum*, the gall rust fungus from *Falcataria moluccana* in Malaysia and Indonesia. Mycoscience 51(2):149–153

Reeb JE (1998) Scientific classification of trees. General Forestry Information FOR-61. University of Kentucky Cooperative Extension Service. http://www.ca.uky.edu. Accessed 19 Nov 2011

Roshetko JM, Evans DO (eds) (1999) Domestication of agroforestry trees in Southeast Asia. Proceedings of a regional workshop held 4–7 November 1997 in Yogyakarta, Indonesia. Forest, Farm, and Community Tree Research Reports, special issue. Forestry Research Institute and Council of Agriculture, Taiwan, Republic of China

Roshetko JM, Mulawarman Purnomosidhi P (2004) *Gmelina arborea*—a viable species for smallholder tree farming in Indonesia? New For 28(2–3):207–215

Roshetko JM, Delaney M, Hairiah K, Purnomosidhi P (2002) Carbon stocks in Indonesian homegarden systems: can smallholder systems be targeted for increased carbon storage? Am J Altern Agric 17(3):138–148

Roshetko JM, Mulawarman, Suharisno, Iriantono D, Harum F (2003) Direktori penyedia benih pohon di Indonesia, edisi kedua (Directory of tree seed suppliers in Indonesia, 2nd edn). World Agroforestry Centre (ICRAF) and Winrock International, Bogor, Indonesia

Roshetko JM, Fay C, Budidarsono S, Tukan JC, Nugraha E, Pratowo N, Manurung G (2004a) Agroforestry innovations and livelihood enhancement in West Java. Final report January 2003 to September 2004. The World Agroforestry Centre (ICRAF), Winrock International and the Indonesia Institute for Forest and Environment (RMI), Bogor, Indonesia

Roshetko JM, Nugraha E, Tukan JC, Manurung G, Fay C, Noordwijk MV (2007) Agroforestry for livelihood enhancement and enterprise development. In: Djoeroemana S, Myers B, Russell-Smith J, Blyth M, Salean IET (eds). Integrated rural development in East Nusa Tenggara, Indonesia. In: Proceedings of the workshop to identify sustainable rural livelihoods, held in Kupang, Indonesia, 5–7 April 2006. ACIAR proceedings no. 126. Canberra, pp 137–148

Roshetko JM, Rahayu S, Wiyono, Prastowo NH (2008) Evaluating indigenous practices for Petai (*Parkia speciosa* L.) seed germination: the effect of seed shelling and seed cutting on germination, growth and survival. Small-scale Forestry 7(3–4):285–293

Simons AJ (1996) ICRAF's strategy for domestication of non-wood tree products. In: Leakey, RRB, Temu AB, Melnyk M, Vantomme P (eds). Domestication and commercialization of non-timber forest products in agroforestry systems. FAO Technical Paper, Non-Wood Forest Products 9. Food and Agriculture Organization of the United Nations (FAO), Rome, pp 8–22

Simons AJ, Leakey RRB (2004) Tree domestication in tropical agroforestry. Agrofor Syst 61(1–3): 167–181

Suhaendi H (1989) A statistical assessment of *Gmelina arborea* L. provenance trials in two locations in West Java (Indonesia). Buletin Penelitian Hutan no. 519. Center for Forestry Research and Development, Bogor, Indonesia, pp 13–34

Tchoundjeu Z, Degrande A, Leakey RRB, Simons AJ, Nimino G, Kemajou E, Asaah E, Facheux C, Mbile P, Mbosso C, Sado T, Tsobeng A (2010) Impact of participatory tree domestication on farmer livelihoods in west and central Africa. For Trees and Livelihoods 19(3):217–234

Tukan CJM, Yuliyanti, Roshetko JM, Darusman D (2004) Pemasaran kayu dari lahan petani di propinsi Lampung. Agrivita 26(1):131–141

Yuliyanti (2000) Analisis pemasaran kayu di propinsi Lampung. Faculty of Forestry, Bogor Agricultural University. Bogor, Indonesia